Renewable and Sustainable Energy Reviews 16 (2012) 5319–5330

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Insights into biofuel development in Burkina Faso: Potential and strategies for sustainable energy policies

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ARTICLE INFO

Article history:
Received 20 September 2011
Received in revised form
14 May 2012
Accepted 20 May 2012
Available online 5 July 2012

Keywords:
Biofuels
Renewable energy
Burkina Faso
Africa
Energy policy
Sustainable development

ABSTRACT

In many African countries, the upswing in oil prices is one factor that favours the adoption and implementation of a national biofuel policy. This trend has a major impact on state budgets and domestic trade balances, while also limiting the access of rural inhabitants to modern energy services. Contribution of biofuels in stabilizing the energy sector, influences ongoing negotiations on the global dynamics of climate change, the reduction in greenhouse gas (GHG) emissions and sustainable development. The question of biofuels as an alternative energy thus depends on international, national and local considerations. Biofuels represent opportunities, e.g., energy independence and security, new national income and employment sources, as well as potential food security problems. African policy makers therefore need to make the right choices to guide the development of biofuel production and use.

This article aims to support the development of a biofuel policy by reviewing the latest technical, economic, environmental and social knowledge so as to be able to evaluate the potential and limits of biofuels in Burkina Faso.

Contents

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http://dx.doi.org/10.1016/j.rser.2012.05.028

1. Introduction

African countries are increasingly interested in biofuels as a way of freeing their economies from the contingencies of the crude oil market. As a renewable liquid source of energy, biofuels can replace petroleum in stationary engines (to produce shaft power or electricity) as well as for transport. They can be used either pure or blended with conventional fuels. Managed sustainably, biofuel channels can help African countries not only to reduce their dependence on oil products but also to strengthen existing agricultural chains.

Burkina Faso, a landlocked Sahelian country located in the mid-west sub-Saharan region, is currently facing a major energy crisis in addition to increasing poverty [1,2]. Over 16% of total energy consumed in Burkina Faso is of fossil origin and the country is a net importer of oil [3]. Energy (fuel, electricity, etc.) prices in this country are inevitably rising due to population growth (> 3.1% in 2009 [4]), expanding economic activity (growth rate of 3.2% in 2009, 4.4% in 2010 and 5.5% forecast by the IMF for 2011) and the continuous long-term rise in oil prices on the international market (62.5% over the last 10 years [5]). Alongside this critical situation, biofuel projects are booming in Burkina Faso (70,000 ha of *Jatropha curcas* plantations claimed in 2009), but there is not yet a formally established market for the resulting products (seeds, seedcake, and biofuels).

In this context, the Burkinabe government plans to implement a policy to reduce the country's dependence on oil products and to establish a sustainable market for products from existing biofuel projects. Inter-ministerial discussions on a set of complementary solutions led to the drawing up of a national biofuel production strategy. The draft of this strategy is based on three different development phases or steps which can be implemented in parallel since they target different markets. However, these strategies need to be analysed in terms of available land and agricultural resources, as well as in terms of their socioeconomic and environmental impacts.

African states have to make choices to guide the development of biofuel production and use. What type of crops should be grown? Where? What production factors should be considered? What techniques are required to process biomass into energy (energy recovery)? What energy recovery chains should be favoured? What development model is most suitable: large or small-scale, contractual or competitive, agro-industrial or decentralized? What indicators are suitable for monitoring the impacts of biofuel use? These choices will necessarily affect the impact of biofuels with respect to food security, income, employment, industrialization, vulnerability for households. The answers to these questions should be tailored to each country's specific situation, which in our case is Burkina Faso.

The first part of this paper presents the agricultural and technical potential of the country. The second part analyses the economic benefits and externalities at different steps of the strategy. The third part reviews the proposals and point to a number of risks and potential impacts of the given steps, and recommends preconditions for successful biofuel development. The aim is to conduct a prospective assessment of issues linked to the implementation of a national biofuel strategy in Burkina Faso, and therefore provide public authorities with guidelines and potential solutions for this implementation.

2. The energy and biofuel context: Agricultural and technical potential

Mainly due to its population growth (3.1% in 2009 compared to 2.3% in 1996 [6]), Burkina Faso's total energy consumption has been progressively increasing. In 2008, it amounted to 3.2 million tons of oil equivalent (Mtoe). Imported fossil energy, which represented 17% of the primary energy balance, consisted of crude oil and refined oil products. In 2008, the share amounted to approximately 564 million USD (i.e., 24% of total national revenue), an average increase of 18% compared to 2006 [7,8]. This has weighed heavily on both the trade balance and public finances.

2.1. Energy situation in Burkina Faso

Energy needs in Burkina Faso are mostly fulfilled by traditional biomass (wood), with 2.7 Mtoe consumed in 2008, i.e., 84% of all primary energy consumed [3,7] (Fig. 1). Energy sources are mainly fuelwood (91%), crop residues (5%), bagasse (3%) and charcoal (1%) [9,10]. Since consumption has exceeded the production capacity, there is no internal sustainability for such a system [11]. This has placed extreme pressure on the natural vegetation cover to meet the demand.

Hydrocarbons (mainly oil commodities) constitute the second energy source after wood (Fig. 1). In 2008, their consumption amounted to 522 Mtoe, an increase of 4.8% compared to 2007 [3,10]. Hydrocarbons are mainly used for transport (62%), electricity production (21%), lighting (5%) and cooking (5%) [3]. Nearly two thirds of the total hydrocarbon balance in 2008 consisted of heavy products such as diesel fuel, distillate diesel oil (DDO) and fuel oil (FO), while lighter products such as gasoline and domestic gas represented only 32% (Fig. 1).

In 2008, energy consumption in the transportation sector, which accounted for 62% of the total hydrocarbon consumption, amounted to 358 ktoe, i.e., an increase of 91% over 10 years. Energy consumed in this sector is consisted of petroleum products, diesel fuel (32%), gasoline (27%) and jet fuel (4%). As a result of soaring Brent crude oil prices on the international market, retail prices of refined oil products have increased by 57% for gasoline, 96% for diesel fuel, and 114% for kerosene over the past 10 years.

Total electricity production (including imports) for 2008 reached 755 GW h (broken down as follows: 64% produced by national thermal plants, 18% by national hydropower, and 18% from interconnections mainly from Côte d'Ivoire (94%)) [3,12]. Importing fossil fuels for electricity production directly impacts energy expenditures in the country [13], which has one of the highest kW h production costs in the world. In 2007, hydrocarbons purchased and used by the electricity sector amounted to 77.1 million USD [14]. Petroleum products for thermal plants benefitted from government subsidies (0.188 USD/l for DDO and 0.35 USD/l for FO) to support this sector and therefore buffer the impact on prices [15]. In 2008, state subsidies amounted to 40 million USD (3.9% of the national budget).

Based on this overview of the energy sector, a strategy for biofuel development in Burkina Faso that aims to substitute or replace imported oil should focus on power generation and transport sectors due to their importance within the country,

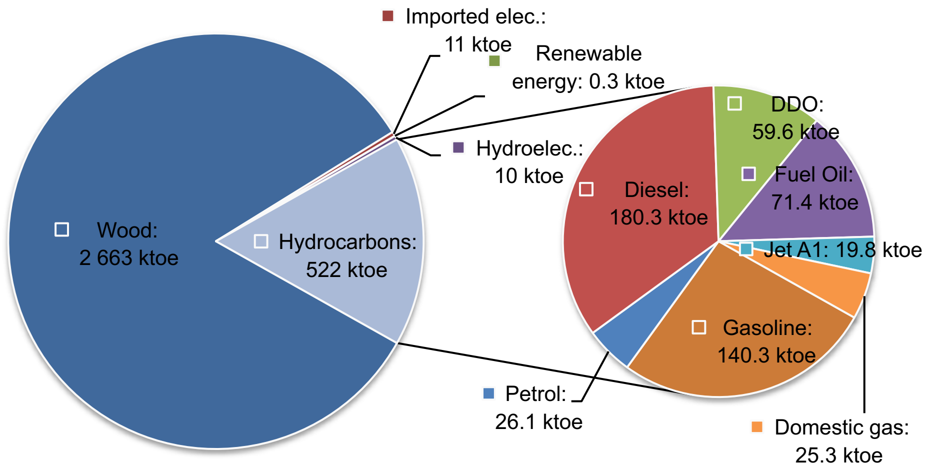

Fig. 1. Primary energy balance in 2008 [3,10].

the hydrocarbons consumption balance (resp. 62% and 21% in 2008 [3]), their economic weight, and the key activities they concern.

2.2. Status of biofuels in Burkina Faso

In the past 5 years, small-scale biofuel development projects have emerged in Burkina Faso. They vary both in their mode of implementation (community farming, individual farming, and commercial farming) and in their objectives. Many projects are in their initial stages and run by national and/or foreign investors. Many farmers throughout Burkina Faso are growing *Jatropha curcas* as a cash crop for biofuel development projects (more than 70,000 ha of plantations claimed in 2009). Plantations have popped up throughout the country since 2007 in response to the 2003 EU Biofuels Directive promoting the use of biofuels for EU transport [16].

With the 2009 repeal of this directive due to environmental and social concerns [17] (potential negative impact of biofuels on food prices and rainforests, the fear that rich companies would drive the poor off their land in order to grow fuel crops, etc.), project holders and government authorities are now looking for local or regional opportunities for the valorisation of plantation production. There is therefore a real opportunity for developing a national or regional market with that supply.

Moreover, reducing poverty in Africa is not possible without improving the agricultural sector, since other sectors are incapable of providing enough jobs to meet the rising employment needs due to population growth [18,19]. In this setting, aside from the problem of national energy requirements, biofuel production could provide an opportunity to fulfill national energy requirements while also generating jobs.

2.2.1. Potential raw materials for biofuel production

As in other countries around the world, while awaiting the commercial development of so-called 2nd generation biofuels (which make use of whole plants), biofuel production options will be limited to 1st generation biofuels in Burkina Faso over the next 15–20 years. That means: (i) production of straight vegetable oil (SVO) from oilseeds, including *Jatropha curcas* and cotton, (ii) production of biodiesel from SVO produced for blends or as a substitute for diesel fuel, (iii) an increase in the production of energy crops such as sweet sorghum or sunflower and other suitable plants (including groundnuts) for ethanol or vegetable oil production.

2.2.1.1. Raw materials for straight vegetable oil/biodiesel production. The most frequently investigated potential raw materials for SVO or biodiesel production in Burkina Faso are *Jatropha curcas*, cotton, soybean, castor plants, and sunflower (see Table 1) [10]. Some other crops such as groundnuts, shea and neem, which are well adapted to the agricultural conditions that prevail in Burkina Faso and have satisfactory processing coefficients, could be potentially considered. However, due to their high prices on the food market and also those of some of their final products (cosmetics), these channels are unprofitable (groundnut oil over 1.67 USD/l, shea butter up to 4.18 USD/kg, oil neem can exceed 6.27 USD/l) [10]. In such conditions, biodiesel produced from these crops would not be competitive with hydrocarbons and would increase market price volatility for these commodities. Cotton and *Jatropha curcas* are the two main oilseed plants cropped in Burkina Faso, while sunflower cropping is just beginning (see Table 1).

Cotton is an annual plant. In Burkina Faso, land under cotton increased steadily from 2000 ha in 1952 to 300,000 ha in 1997, 400,000 ha in 2002 and peaked at 716,000 ha in 2006, followed by a slump to the current level of 450,000 ha. It is the main oilseed crop (22% oil content) grown in the country [10] and Burkina Faso is one of the biggest producers in sub-Saharan Africa; production was estimated at 731,665 t in 2006 [20], but dropped to 529,620 t in 2011 and 450,000 in 2012. However, soaring food prices, the crisis in the cotton sector and the demand for animal feed has led to a dramatic increase in cottonseed prices, thus making imported fossil oil cheaper than cottonseed oil.

Jatropha curcas is a perennial plant which requires 3 years of growth before the first harvest. Recently, *Jatropha curcas* has received considerable attention as a potential biofuel raw material. Based on the reported 70,000 ha of *Jatropha curcas* grown in the country [10,21], 12,000 to 48,000 m^3 of biofuel could potentially be generated [3,8,10,21,22], representing 5–18% of diesel fuel consumption in Burkina Faso in 2007. Many experiments have been carried out to assess potential uses of *Jatropha curcas* oil blended with diesel fuel or as transesterified oil (biodiesel) [23,24]. As shown in Table 3, the calorific value and cetane number of *Jatropha curcas* oil are comparable to those of diesel fuel, but its viscosity is much higher, which can cause problems during pumping and injection of this fuel into engines [25].

Jatropha curcas is a traditional crop in Burkina Faso and its oil is traditionally used to manufacture soap. Much of the current interest in *Jatropha curcas* is focused on the benefits of its toxicity [26], i.e., the resulting oil is not edible and thus the plant can be used to protect crops from livestock and, moreover, it grows well on marginal land. Hence, the plant is particularly attractive since

Table 1
Potential feedstock for SVO/biodiesel production in Burkina Faso, 2008 [10].

Type of crops	Ha or estimated feet	Average yield[a]	Average/theoretical oil yield	Price per kg of seed	Advantages	Disadvantages
Jatropha curcas	560,093 feet[b]	1.5 kg of seed/feet[c]	0.5 l of oil/feet, i.e., 0.14–0.6 m^3/ha depending on the density[d]	\$US 0.7–0.21/kg of seed	– Inedible plant, used as a hedge (protection against animals and desertification). – Soil quality and rainfall less important – Perennial crop – Simple extraction process with locally produced presses – Nitrogen-rich seedcake	– First harvest after 3 years – Seedcake cannot be used for livestock feed – Risk of competition for land needed for food crops – Wild plant for which little agronomic data is available – Possible toxic effects of soil by using seedcake as fertilizer – Limited market for oil as fuel or as raw material for soap manufacturing
Cotton	569,858	0.68 t/ha of oilseed	0.125 m^3/ha	\$US 0.6–0.20/kg of seed	– Main cash crop in Burkina Faso – Seedcake can be used for livestock feed – Well-structured production and supply chain – Existing agroindustrial units – Large accessible food and energy market	– In competition with food market (demand for oil currently not met) – High price of cottonseed: prices linked to world prices of various edible oils – Low oil yield per hectare
Groundnuts	310,597	0.80 t/ha	0.35 m^3/ha	\$US 0.27–0.63/kg of seed	– Good oil yield per hectare – Seedcake used for livestock feed – Legume = > soil nitrogen enrichment – Oil has good fuel properties	– In competition with food – Competition for labour for food production – Price volatility based on world prices of edible oils – Cultural and ethical barriers in the use of the oil as fuel – Seeds too expensive for small-scale farmers
Soybean	5,141	1.25 t/ha	0.28 m^3/ha	\$US 0.29–0.42/kg of seed	– Large accessible food and energy market—seedcake used for livestock feed – Legumes= > soil nitrogen enrichment – seeds available – support for the sector through the ESOP[e] – Seeds available	– Not among usual food habits – Competition with food and feed market – Oil with high gum content
Sunflower	Currently being tested	1.2–1.5 t/ha	0.53–0.66 m^3/ha	–	– Good oil yield per hectare (irrigated mode) – Cake usable for livestock feed – Not for human consumption – Good outreach in West Africa Region: Office of Niger, Mali, Burkina Faso – Oil has good fuel properties	– Risk of competition for land and water resources – Little agronomic data available in Burkina Faso (unknown to farmers) – Competition with food production for labour – Price volatility based on world prices of edible oils – Non-hybrid seeds no longer available in the sub-region (seeds are expensive and farmers cannot produce their own seed).

[a] Yields correspond to the national average for the last five seasons, Source: Burkina Faso Ministry of Agriculture, Water and Fisheries Resources.
[b] Burkina Faso Ministry of Environment and the Living Environment, Census of *Jatropha curcas* plants, 2006.
[c] Data from Professor Ouedraogo Makido's experiments and from the report "*Jatropha curcas* and *Jatropha gossypifolia* under different climatic conditions in Burkina Faso, crops and farms, 1985" by Tahirou Zan.
[d] Depends on the density (too variable due to project developers) and on estimated yields previously obtained in Burkina Faso using local varieties.
[e] Business Service and Producer Organizations.

it theoretically would not displace food crops [27]. However, in practice, this is erroneous reasoning since, if cultivation of *Jatropha curcas* were to be substantially extended (with no attention paid to the amount of land used), it could lead to real competition with food crops for land. This is a likely situation since the plant requires good land to achieve high yields, thus posing a threat to lands used to grow food crops. Indeed, project holders who aim to make a profit growing *Jatropha curcas* for biofuel production are sowing this species on good soil in regions with optimal rainfall conditions, i.e., on fertile land in southern Burkina Faso. Another negative aspect concerns the toxicity of the resulting seedcake after oil extraction, i.e., it cannot be used for livestock feed, thus calling into question the cost-effectiveness of this species for biofuel production [26]. *Jatropha* seedcake is now mainly used as feedstock for biogas production through anaerobic digestion [28–30]. According to Devappa et al. [31], *Jatropha curcas* seedcake has a specific methane production potential of 0.394 m^3/kg of total solids. The biogas can be flared to produce heat or burned in engines to produce shaft power or electricity [28]. Farmers can also use the solid residue as a soil amendment [32]. Nevertheless, once the bacterial flora is activated and adapted to a substrate, the anaerobic fermentation process requires a continuous supply of seedcake. A substantial amount of cake must therefore be available, which is currently not yet possible. This energy production option will only be interesting when the oil mills are able to run at full throttle.

Another interesting use of *Jatropha* seedcake is as fertilizer since it has a high nitrogen content. Although few studies have focused on this topic and the potential toxic effects of this meal in the soil is highly controversial, most operators use it as fertilizer to increase *Jatropha* plant yields [26,31,33,34]. Malian market gardeners are also quite infatuated by using this organic fertilizer to enhance their food crop yields. The cake product is sold in Mali for $US 0.30/kg. This market could increase the profitability of the production line, but it is hard to foresee what the market prices would be in the future when large quantities of *Jatropha* seed are available.

Jatropha curcas dried fruit consists of about 35–40% of shell and 60–65% of seed (by weight) [35]. The low-density husks have a calorific value slightly lower than that of wood, which means that it is not cost-effective to transport these husks over long distances [29]. *Jatropha curcas* husks are more useful as fuel for farmers and could therefore contribute to reducing pressure on forests and woodlots. Husks can be used directly as domestic fuel instead of wood, or in briquetted form.

2.2.1.2. Raw materials for bioethanol synthesis. In Burkina Faso, sugarcane, sugar beet, sorghum, cassava, and maize crops could, technically, provide feedstock for a bioethanol plant (Table 2). However, sorghum, cassava, and maize are currently grown for food. Given the already relatively high prices of these commodities on the food market, and the current production volume, using them as feedstock for bioethanol production could increase the current instability of most food markets.

Although sugarcane cultivation requires large amounts of water, this crop has a real bioethanol production potential. It has the highest alcohol potential (estimated yield: 4000 l/ha) and processing generates cellulosic biomass (bagasse) as a waste product which could cover energy needs via the distillation of ethanol from the aqueous medium as well as through other processes [10]. In 2007, 3700 ha of land was under sugarcane and national sugar production amounted to around 30,000 t, whereas domestic demand was estimated at 50,000 t [36].

Other products such as molasses and sweet sorghum are also possible raw materials for bioethanol production. Molasses is a by-product of sugarcane or sugar beet processing. The potential yield of ethanol from molasses is 45–60% and depends on the amount of fermentable sugars [37]. Sweet sorghum has several advantages despite its lower alcohol yield (600–1120 l/ha,[10]). The plant has a relatively short growth period, so several harvests are possible each year, and it is drought resistant. The stalk contains about 15–17% sugar [37]. Yields are estimated at around 60 l/t of stalks [38]. By-products are wastes which can be used to produce energy, and grain which can be used for food. But unfortunately, West African countries have no experience in producing ethanol from sweet sorghum. However, research is currently underway on its possible use for both energy production and food.

2.2.2. Appropriate technological pathways for Burkina Faso?

At present, depending on the industrial context, three types of first generation biofuels can be produced in Burkina Faso: straight vegetable oil, biodiesel and bioethanol.

Table 3
Comparison of the physicochemical characteristics of vegetable oils with those of diesel fuel [40,46,67].

Oil	Density at 20 °C	Flash point	Cetane number	NCV (kJ/kg)	Kinematic viscosity (mm^2/s)	Pour point (°C)
Diesel fuel	836	93	50	43 800	3–7.5	< −5
Cotton oil	921	243	35–40	36 780	73	−1
Palm	915	280	38–40	36 920	95–106	31
Copra	915	–	40–42	37 100	30–37	20–28
Rapeseed	915	320	32–36	37 400	77	−11
Sunflower	925	316	35–37	37.750	56–61	−5
Soybean	920	330	36–38	37 300	58–63	−4
Groundnut	914	258	39–41	39 330	85	9
Jatropha curcas	920	240	45	38,850	55	3
Flaw	920	241	35	39,307	45–50	1.7
Corn	915	277	98	39,500	60–64	−1.1

Table 2
Potential feedstock for bioethanol production in Burkina Faso, 2008 [10].

Type of crops	Ha	Average yield[a]	Average/theoretical ethanol yield	Advantages	Disadvantages
Sugarcane	3500 ha	71 t/ha	4–6 m^3/ha	– High alcohol potential (whole plant used) – By-product: bagasse for energy production – Secure supply for an industrial scale crop – No identified impact on the price of sugar – Best environmental balance among the different crops devoted to ethanol production	– Cost-effective only at an industrial scale – Irrigated crop: competition for water resources – Heavy investment required – Environmental impact of industrial processing units (vinasse, etc.)
Sweet Sorghum	Currently being tested	7–14 t/ha[b]	0.6–1.12 m^3/ha	– Seed availability – No competition with food (only the stalks are used) – Use of by-products (biofuels, animal feed, heat)= > improved income – Nutritional supplement (sugar) – Two harvests per year if irrigated	– Industrial process – Centralized process – No experience with producers

[a] Yields correspond to the national average for the last five seasons, Source: Burkina Faso Ministry of Agriculture, Water and Fisheries Resources.
[b] Estimated stalk yield in experiments conducted with sweet sorghum in Mali in rainfed conditions. No data was available for irrigated conditions in Burkina Faso.

2.2.2.1. Straight vegetable oil. SVO from oilseeds can be produced in small or large crushing units equipped with filtering and decanting devices. The technology is fully proven and can be used from a village up to an industrial scale. As shown in Table 3, even though it has low viscosity and a high cetane index, the physical properties of SVO do not differ completely from those of diesel fuel. SVO can thus be used either mixed at a ratio of up to 30% in diesel fuel or up to 100% in static diesel engines. The overall fuel performance of SVO and the many problems encountered in its use are widely documented [39]. However, it is important to note the absence of quality standards for vegetable oils used as fuel [39]. If the conditions for good SVO combustion are met, its performance and emissions are comparable to those of diesel fuel or fuel oil [10,40,41].

2.2.2.2. Biodiesel. Biodiesel is a monoester obtained by reacting vegetable oil with primary alcohols. This reaction, which is slow and reversible, is optimized by using chemical or enzymatic catalysts. As shown in Table 4, biodiesel has low viscosity and a high cetane index close to those of diesel fuel. Biodiesel can be used in any diesel engine without any major modifications. But as the calorific value of biodiesel is slightly lower than that of diesel fuel, using pure biodiesel results in 2–5% power loss and 6–9% higher fuel consumption [42].

In Burkina Faso, special attention should be paid to the type of alcohol intended for the chemical process. Methanol, which is used worldwide, is a by-product of the oil industry and is not produced in Burkina Faso or in most African countries. If methanol were to be used, it would have to be imported via the international market, which would make the production system less profitable and also less secure. To avoid this dependence, many companies are conducting research into new processes for the production of biodiesel from ethanol. This represents an opportunity for Burkina Faso, as one plant for the production of ethanol from sugarcane is already up and running. Nevertheless, such a biofuel channel requires industrial scale units and a well-structured ethanol sector which, in Burkinabe conditions, would only reach maturity in the long term.

2.2.2.3. Bioethanol. As mentioned above, in the conditions that prevail in Burkina Faso, sugarcane may be the most appropriate raw material for producing bioethanol. However, sugarcane cultivation requires substantial water, and distillation requires major investments. Distillation consumes considerable energy as the ethanol must be very anhydrous. A mixture of 10% bioethanol and gasoline could be used in all gasoline engines without any modification. However, the calorific value of bioethanol is almost twofold lower than that of gasoline, so the engine consumes twice as much fluid to generate the same amount of energy. Otherwise the two fuels have very similar properties (Table 5). However, as bioethanol ignites much faster than gasoline, it is possible to incorporate less than 10% without modifying the engine. Above 10% (up to 30%), the settings would have to be adjusted, or (> 30%) either an alcohol engine, alternatively, a "flexfuel" engine that fits any ethanol/gasoline mixture would have to be used [43].

3. Strategies for renewable fuel production in Burkina Faso

Given, (i) the growing pressure on the trade balance due to the cost of oil products (related to the price volatility of petroleum products), (ii) the negative effect on socio-economic development due to these costs, and (iii) the need to move towards cleaner energy sources to reduce greenhouse gas emissions, the Burkinabe government has drawn up a national strategy for the production of biofuels to replace hydrocarbons. The national policy objectives are to strengthen farming, to reduce disparities between the urban and rural sectors, to meet domestic energy needs rather than producing for export in order to create direct added value, and to reduce the country's dependence on imported energy. In the long term, if well thought out, this strategy should strengthen the national economy and improve the well-being of rural populations with respect to food safety and environmental protection.

3.1. Development phases for the substitution of fossil fuel by biofuels

Based on an analysis of national energy needs, the agricultural potential and technological opportunities, and given the increasing number of plantations which are starting to produce oilseeds despite the fact that there is not yet a real established market for biofuel, three expansion phases are possible in terms of their technical feasibility and future development [10]: "Step 1" involves replacing fossil fuels by raw vegetable oil for electricity production. "Step 2" involves adding a short supply chain, including local production of raw vegetable oil, for power/rural electrification. "Step 3" involves the continued use of industrially produced biodiesel and/or bioethanol for transport.

3.1.1. "Step 1". Short-term use of raw vegetable oil to generate electricity

The first step in the implementation of this new energy strategy concerns the production of RVO to supply national electrical power plants and decentralized rural electrification units. Using RVO to generate electricity will reduce the economic

Table 5
Physicochemical characteristics of ethanol and gasoline [43].

Properties	Gasoline	Bioethanol (95)
Density at 20 °C (kg/m^3)	0.75	0.79
Calorific value (LHV) (kJ/kg)	44 000	26 900
Combustion value (g air/g fuel)	14.60	8.9
Boiling point (°C)	27–225	78
Vapour pressure at 38 °C (kPa)	48–103	16
Flash point (°C)	−43	13
Auto-ignition point (°C)	257	423
Octane number	98	106

Table 4
Physicochemical characteristics of some oil esters [68].

Properties	Diesel	Methyl ester rape	Methyl ester *Jatropha curcas*	Ethyl ester cotton	Methyl ester soybean
Density at 20 °C (kg/m^3)	836	880	870	855	855
Viscosity at 40 °C (mm^2/s)	3.3	6.7	4.20	4	4.1
Calorific value (kJ/kg)	43 700	37 700	34,400	37 500	37 300
Flash point (°C)	63	171	191	110	171
Cetane number	50	49	57–62	52	51
Cloud point (°C)	< −5	−3	–	1	2

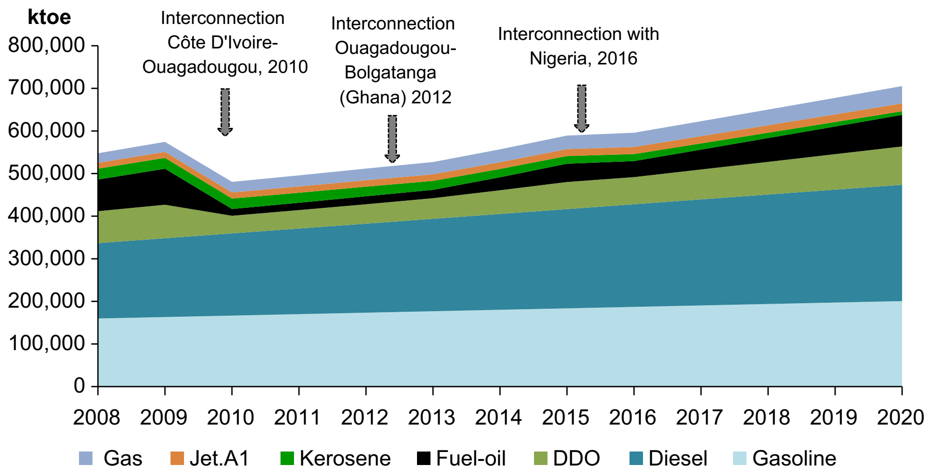

Fig. 2. Hydrocarbon consumption forecast [3].

impact of oil imports while enhancing access to energy services in rural areas in accordance with the recommendations of the White Paper for a Regional Policy on Access to Energy Services [44]. By 2011–2012, it is planned that a number of electrical power stations will use RVO instead of imported oil. Based on the Burkinabe Ministry of Energy forecasts (Fig. 2) concerning the use of oil products for electricity production, technical blends, i.e., a maximum ratio of 30% [39], and the potential supply channels of national oilseed, "Step 1" will ensure the production of 20,000–35,000 m^3 of RVO to supply electrical power plants [39,45,46]. Technically speaking, once filtered, RVO made from oilseeds could also be used in stationary engines with no major modifications [39,41].

"Step 1" has the following main guidelines [10,45]: (i) RVO production is dedicated to the domestic market until 2020/2025; (ii) land required for RVO production will be limited to 200,000 ha, i.e., 2.2% of available farmland in Burkina Faso; (iii) RVO channels will be set up to supply the power company, along with small processing plants (possibly using *Jatropha curcas* oil or other oil products) or centralised plants (e.g., using cottonseed oil).

This "Step 1" is flexible and requires only limited investments. Its implementation would provide an outlet (and possibly even a sustainable market) for the recently established *Jatropha curcas* plantation production. This means Burkinabe farmers rather than oil multinationals would receive payment. If this strategy is efficiently applied in the long term, it could have a positive impact on (i) the national energy bill, (ii) the cost of electricity for households, businesses and the government, (iii) the state subsidies used to pay for imported oil products for the generation of cheaper power for consumers (40 million USD, i.e., 3.9% of the 2008 national budget [47]).

3.1.2. *"Step 2". Short supply chain, local production of raw vegetable oil for power/rural electrification*

"Step 2" concerns the development of short local RVO production channels for power and/or electricity generation to meet the need for energy services in rural areas. After the implementation of "Step 1", the experience gained by the different stakeholders (farmers, agroindustries, the state) concerning biofuels experience (farming, processing, controlling ...), reliable agricultural networks can be set up to ensure effective development of local energy channels in rural areas. In this step, producers are also consumers. A community that grows oil crops could thus ensure the production of enough RVO to fulfil its own energy needs. This would require the development of short-circuit energy production strategies, which appear to be particularly well-suited to conditions in Burkina Faso. The availability of low cost local fuel to be used in the vicinity of the production area would allow farmers to sidestep the problem of soaring oil and distribution costs and thus ensure their energy independence.

The success of this step depends partly on the successful establishment of decentralised units for RVO production and use [48] Based on the same pattern as a multifunctional platform, i.e., built around a decentralized plant for mechanical and electrical energy production, in this case small decentralized oil mills could produce their own biofuel [49]. If ecologically well managed, this could be a sustainable way to provide energy services for productive ways to enhance social and collective development. In addition, this step could provide an outlet for *Jatropha curcas* which is currently being sown in rural areas. An analysis of the planned oil demand estimated the potential RVO market at 5000 toe in 2012 to provide energy in rural areas (producing some electricity, power to pump drinking water and water for irrigation), which could increase to 50,000 toe by 2025 [45].

3.1.3. *"Step 3". Industrially produced biodiesel and/or bioethanol for the transport sector*

Once "Steps 1 and 2" are up and running, the production of biodiesel or bioethanol could be centralized to provide an alternative to the use of diesel fuel or gasoline in the transportation sector. This step involves replacing diesel fuel by up to 100% and incorporating up to 10% of bioethanol in gasoline for light vehicles. As transport accounts for the consumption of over 60% of all imported oil, and given the ongoing significant increases in oil prices, implementing this step would significantly reduce the overall cost of oil in Burkina Faso. Note however that the technical and economic cost-effectiveness of these two channels is possible only on an industrial scale (above 20,000 t/year [50]), which implies producing huge quantities of raw materials and significant upstream investments. This scale is not possible at present as stakeholders first need to gain experience in the cultivation of energy crops.

An analysis of the projected oil demand led to an evaluation of the potential market for biodiesel and bioethanol at: (i) 20,000 toe for bioethanol blended with gasoline at a ratio of 10%, (ii) and 90,000 toe for biodiesel blended with diesel at a ratio of 30% [45].

3.2. Implementation of the three development steps over time

The most appropriate itinerary for Burkina Faso would be to first implement the short-term "Step 1", thus establishing the conditions required to awaken stakeholders' interest in "Step 2", followed by "Step 3". Biofuel production must first meet the needs of the electricity sector. The promotion of biofuels in rural areas from 2012–2013 should enable most of the energy needs of rural populations to be met by 2015 or 2020. A cropping area of 200,000 ha will be required for this market [45].

Implementing "Steps 1 and 2" (sequentially) will allow enough time to meet the conditions required to ensure the technical and economic feasibility of "Step 3". Starting in 2015, the use of biofuels to meet transportation needs will be based on the positive results of the two first development phases in terms of feasibility. The production of biodiesel will then gradually replace diesel fuel for transport. Before 2020, the first production of anhydrous ethanol as an alternative to gasoline will start after feasibility studies on its market use [45]. An additional 300,000 ha could be required for this market [45].

4. Discussion

Three development phases were identified concerning the implementation of a national strategy for biofuel development in Burkina Faso. In this section, we discuss the different types of risks and impacts associated with the development of these steps and more generally with the introduction of biofuels in the country, under the prevailing conditions. A number of pre-conditions are thus highlighted and some recommendations concerning the feasibility of this strategy are proposed.

4.1. Impacts and risks associated with biofuels

4.1.1. Impacts and risks associated with modes of production

Three production modes are currently encountered in projects under way in Burkina Faso: production on communal lands, smallholder production and agroindustrial production. All of these production modes have social consequences and impacts on the land, both in terms of deforestation and competition for fertile agricultural land or pasture for livestock.

The communal land production mode, which is possible in all three steps, is likely to create work for rural inhabitants (planting and harvesting, for both farmers and non-farmers) and have a positive impact on municipal revenues thanks to the income generated by these operations.

The smallholder production mode, although feasible in all three steps, is most adapted to "Step 1" (biofuel production for electricity generation) and "Step 2" (power/rural electrification). But farmers require a rapid return on their investment (within the current cropping year) and would not be able to immobilize their land solely for biofuel production (for 2–3 years in the case of *Jatropha curcas* cropping). However, farmers with sufficient land could devote part of their land to biofuel production in association with other crops with the aim of diversifying their income.

With the agroindustrial production mode in "Step 2" (power/rural electrification) and "Step 3" (transportation), the main objective is to maximize productivity. However, the use of fertile and irrigated land could lead to competition with food cropping and water resources. There would be an impact on land tenure and deforestation, as experienced in Malaysia and Indonesia with the development of oil palm plantations at the expense of primary forest, thus boosting the risk of environmental degradation and land usurpation [51,52].

Indeed, it is essential to respect existing systems which have proven their efficiency in Africa. West African family farming is characterized by high resilience and ensures household food security: diversification, adaptation and innovation with limited capital, community anchorage (solidarity and mutual assistance, membership networks and associations, etc.), natural resource management, etc. [53]. The increase in large farms could precipitate the emergence of landless farmers in some areas, and in turn lead to rural outmigration. It is thus crucial to focus on family farming rather than large agroindustrial complexes. However, carefully combining the two production modes, along with appropriate legislation and strong support for family agriculture, could ensure the sustainability of the system with a positive social impact and optimal development. The contract farming model, where an organization invests financially and provides the necessary technologies, seeds, and fertilizers to small local producers in exchange for exclusive rights to purchase the production at a contractually preagreed price, appears to be the best way to protect the interests of African farmers. Several projects are currently underway in Burkina Faso based on this model, but they are too recent for their actual effects to be evaluated.

4.1.2. Biofuel production and food security risk

The main disadvantage of biofuel production is that it can compete with food production [54]. Domestic biofuels can threaten food security through different ways: competition between outlets, i.e., whether the oil is sold on the food or energy market (the case of soybean, peanut and sunflower); competition between products for land and water (case of *Jatropha curcas* in monoculture or intercropping systems, and of sugarcane, which is a water-thirsty crop), or for labour and capital allocation within households (cash crops).

Competition between oil outlets is currently not a problem in Burkina Faso. The only edible oil produced in the country comes from cottonseeds, but the quantities involved only fulfill half of the national demand. The country imports palm oil from Côte d'Ivoire and Asia (at very low prices) to meet the demand. Moreover, there is an increased demand due to population growth. The recent international market volatility with respect to cotton fiber has led to uncertainty on the future of the Burkinabe cotton oilseed market. It has actually been noted that the drop in international cotton fiber prices has had a reverse effect on the domestic market price of cottonseed oil. Promoting new oilseed crops (sunflower, soybean, etc.) could thus help to meet the national demand for edible oil. Stimulating these sectors could benefit both the food and energy markets. These plants have the advantage of allowing farmers to seek the best market opportunities by targeting either the food or energy market depending on which offers the best price. To control the two channels and therefore secure the food market, companies such as national electricity producers and fuel distribution companies could be allowed to buy RVO at a floor price set by state authorities. This would enable farmers to be free to sell their products on the food market if prices were higher while selling their surplus or lower quality oils on the energy market.

The choice of crops, techniques and farming methods needs to be considered on a case-by-case basis in order to limit competition with food crops for land, water, labour and capital. It may be possible to reduce competition by growing *Jatropha curcas* in hedges or in association with food crops. However, interactions between *Jatropha curcas* and food crops have yet to be clarified. Unlike *Jatropha curcas*, cropping other energy plants (soybean, sunflower and sugarcane) can overcome certain risks (fluctuating prices, no delay on return on investment, specialization and dependence) while having the significant advantage that their

seedcake can be used for livestock feed, with a positive impact on food security.

However, food security is not simply a matter of production capacity. Food insecurity may also be an upshot of badly functioning markets, inefficient agricultural policies and certain social factors. Food insecurity is linked to the more global problem of poverty.

Biofuels could still have a positive impact on food security. One cause of low plantation yields in Burkina Faso is the lack of mechanization, partly due to the fact that farmers cannot afford to buy fuel. Yields could be increased by producing biofuels themselves and using them for their agricultural machinery ("Step 2": power/rural electrification), with more irrigation and better worked land. Synergies between energy and food are indeed possible: by intensifying production via mechanization, and increasing per-hectare yields, thereby curbing the land access problem; but also by enhancing food crop use through processing and preserving products, thereby extending their shelf life, and facilitating access to food products thanks to increased transportation, thereby improving their spatial distribution. Efforts are needed to take full advantage of these synergies.

Burkina Faso apparently still has 5000,000 ha of available land [10,55]. If the government agrees to buy SVO at a reference price to supply power plants, this would encourage farmers to produce oilseeds. They would obviously benefit if they could sell their products at a good price on the food market, but in the worst case, it would be possible for them to sell them on the energy market at the floor price set by the state. This would promote synergy rather than competition. However, analyses are required to determine the floor price.

4.1.3. Assessment of land requirements for biofuel production

Concerning competition for land, agricultural land sown each year with cereal crops represents only 45% of the potential cropland [45], so there is still land available for new crops. The land required to produce biofuels depends on the type of crop used (yield and oil content), the planned production level and the model applied. Around 15 ha of *Jatropha curcas* would be required to meet the energy requirements of a rural community of 2500 people with a multifunctional platform in "Step 2". The land required to replace 30% of imported diesel fuel to generate electricity in the national company's power stations in "Step 1" represents less than 6% of the country's arable land [10].

In Burkina Faso, the quantity of biofuel needed for power generation and to meet the energy needs of rural areas (agricultural mechanization, irrigation, multifunctional platforms) is estimated at 70,000 toe [45]. These needs could be fulfilled by producing RVO (mostly *Jatropha curcas*), whose yields range from 0.2 to 0.8 toe/ha with the average yield expected to increase to 0.6 toe/ha over time. On a yield basis of 0.35 toe/ha [56], the maximum land requirement for this market sector is 200,000 ha, or 2.2% of available land. The land requirement is even lower when using species such as sunflower, which have higher yields while also generating seedcake that can be sold as livestock feed.

Regarding the transportation sector, the market is estimated at 90,000 toe of RVO for biodiesel and 20,000 toe for bioethanol [45]. Regarding the bioethanol channel, sugarcane is the crop with the highest potential but requires irrigated land and industrial-scale production. It is nevertheless the most attractive species, with a yield of 4000–5000 l/ha [10,21]. With a production volume of 20,000 toe, it is possible to blend up to 10% of bioethanol with gasoline in "Step 3". This corresponds to a production volume of 30,000 m^3 of ethanol, i.e., 6000–7000 ha of irrigated sugarcane based on predicted yields [10,21]. On the same conservative basis and taking into account the fact that bioethanol is produced from high-yielding sugarcane varieties, land requirements for the second segment dedicated to energy production for transport is estimated at 300,000 ha, or 3.3% of available land.

Overall, a maximum total of 500,000 ha is likely, which corresponds to 6% of the arable land in Burkina Faso [45,57]. This land requirement seems acceptable (especially if access to energy in rural areas leads to higher yields) and would not endanger land availability to fulfil food security needs. However, it remains to be determined whether the land that could be targeted is actually available, i.e., that it is currently not cropped, grazed or otherwise appropriated [58]. Much of the 5000,000 ha of land claimed to be available is actually already used by local inhabitants to ensure their survival: gathering, transhumance, collecting fuel–wood, etc.

4.1.4. Environmental impacts of biofuel production

Substituting biofuels for hydrocarbons would help to avoid the emission of tons of CO_2 that could be sold on the international carbon market (Clean Development Mechanism (CDM) or Voluntary Market) [59]. Use of this new renewable source of energy in rural areas would help reduce pressure on forests. This is a positive ecological asset of decentralized forms of production.

Nevertheless, biofuel production from raw materials requires energy for farming, transport and conversion into the final product, and thus has environmental consequences. Concerning *Jatropha curcas* production, it is actually impossible to foresee the environmental impacts of developing this plant as a field crop. Although *Jatropha curcas* can grow on degraded soils with low rainfall, like any crop, yields are better on rich soils, with a satisfactory supply of water, fertilizers and pesticides. This of course reduces its positive impact on the environment. The impact of implementing biofuel channels depends on the selected technical pathway and production mode.

Concerning ethanol production from sugarcane, one major limiting factor is the pressure on water resources since water is needed both to grow and process sugarcane. Many project developers are interested in growing sweet sorghum for ethanol production. However, like *Jatropha curcas*, currently no reliable data are available on the cultivation and potential yield of this plant in Burkina Faso. Problems of access to inputs and water resources are likely to be similar to those for sugarcane.

4.2. Conditions and recommendations for the implementation of biofuel initiatives

The different steps will only be implemented if a set of preconditions related to priorities already outlined in national development policies (food security, environmental protection, support for traditional farming, etc.), including respect for local communities, are actually met. To this end, it is essential to draw up a proper legal and institutional framework for biofuels in accordance with agricultural policies.

4.2.1. Sustainable development

The main precondition is that biofuel development must be in line with food security priorities. Food security issues are at the heart of socioeconomic development priorities. Depending on the objectives outlined in the Strategic Framework for the Fight against Poverty (CSLP), the development of biofuels by 2015 should be part of the reinforcement of conditions required for food security and the reduction of disparities, inequalities and poverty in Burkina Faso [60]. It is mainly in the field of water management and access to new land that the biofuel policy should strive to avoid the appropriation of irrigable land for monocropping of *Jatropha curcas*. It should instead, by allowing

the local production of biofuels for local consumption, provide support for irrigation in rural areas and for the mechanisation of agriculture.

The second precondition is that biofuel development must be in line with environmental protection and biodiversity objectives. Biofuel should be produced in compliance with the different laws, regulations and international conventions on desertification, climate change and reducing greenhouse gas emissions ratified by Burkina Faso. Biofuel development should comply with biodiversity principles by fostering sustainable agroforestry, the use of crops that minimize fertilizer and pesticide requirements, and by promoting the *Jatropha curcas* intercropping. The environmental aspects must be taken into consideration through a research program and monitoring a set of specifications for the cultivation of biofuel crops.

The third condition required for sustainable development is that biofuel development be respectful of small producers. Traditional farming remains a mainstay of rural life. It is essential that rural farmers participate in biofuel production.

4.2.2. Institutional governance

To an even greater extent, the sustainable development of biofuels in Burkina Faso deeply depends on drawing up a suitable national legal and institutional framework [61]. Mainly, regulatory actions and support for these new sectors must be consistent with (and not work against) the agricultural development policy the government is seeking to promote [62].

With the current threat to food security, but also in the setting of the fluctuating competitiveness of biofuels due to the price volatility of crude oil, and the limited financial capacities of rural communities, effective national public policies are needed to guide, protect and encourage stakeholders during the emergence of local production chains. This is not easy because many different operators are involved in the biofuel production chain. Private stakeholders also play a role in building these production chains. The interplay between public and private stakeholder as well as between local, national and global stakeholders is complex. Relations can sometimes be conflictual but also alliances can be formed between private companies and the state, between foreign companies and local ventures or traditional authorities, as well as between regional authorities, NGOs, foundations and international aid agencies [63]. This interplay affects political choices that govern the consequences of investment in this sector.

Another important point is that local people must be empowered to better defend their rights of access to land and natural resources they use. Currently, their contribution is often limited to rapid approval of the projects put forward by elders, officials or the 'elite'. According to Vermeulen and Cotula [64], local people are obliged to negotiate with investors (consultation, consent and compensation) because they often have no economic and institutional alternative (extreme poverty, lack of jobs, climate dependency). The chosen framework must reduce the information and power asymmetries between private companies and local social groups by strengthening the capacity of the latter to negotiate [65]. A corollary requirement is profit sharing, which is currently not envisaged in the national policy. This is not as straightforward as it may seem, because some investors take advantage of both the lack of local or national governance and insufficiencies in the legislative framework (land, foreign trade, taxation, infrastructure, etc.) [66]. The state faces the difficult challenge of adopting regulations and mechanisms to take advantage of foreign investment in biofuels while preserving the livelihoods and interests of local people.

In summary, a number of conditions need to be met to ensure that the advantages of biofuels outweigh the disadvantages in Burkina Faso. Among them, it is essential that: (i) the domestic use of biofuels takes priority over exports; (ii) models of agroforestry and intercropping involving small local producers and family farming take priority over agri-business; (iii) investment in *Jatropha curcas* does not only concern the best agricultural land; (iv) wetlands are protected against overexploitation by sugarcane cropping; (v) the emergence of decentralised systems is a priority; (vi) crops dedicated to the biofuel production do not compete with food crops; (vii) the edible oil market is regulated; (viii) technical obstacles to production and processing are removed; and finally, (ix) further knowledge is obtained on appropriate plant species, mainly *Jatropha curcas*.

5. Conclusions

In this paper, we have shown how setting up biofuel channels could be an opportunity for Burkina Faso. The success of such an initiative would enable the country to develop its own energy services while reducing its energy dependence. In addition, the energy supply pressure on the natural environment would be reduced via the diversification of energy resources.

We have discussed the impacts and potential limitations of three different steps. Step 1 could be implemented easily and rapidly given the current production of *Jatropha curcas*, which will soon be harvested to produce vegetable oil for electricity generation. Short supply chains for local use (Step 2) are certainly promising in terms of creating income in rural areas and in promoting local development (electrification, social services, food processing, food preservation, agricultural intensification). The required technology is relatively simple and cheap but the organization of local stakeholders and dedicated projects in rural areas needs to be carefully thought out. Other options concerning biofuel production and use (which could be centralized to different extents) were analyzed. Some (Step 3) appear to be technically risky and are not advisable in the short term (ethanol or biodiesel for the transportation sector). These steps are now an integral part of the national strategy. The priority of the Burkinabe government energy policy is to develop biofuels for the domestic energy market. In this setting, it is unfortunate that the biofuel production strategy is mainly based on *Jatropha curcas*. Other oilseed crops which offer greater benefits (edible seedcake, possible sales on both the food and energy markets, higher oil yield, etc.) could also be grown in Burkina Faso.

Projects dedicated to biofuel crops and, to a certain extent, to industrial plantations, have potential advantages for Burkina Faso. The minimum requirement is to reduce energy dependence to cope with the continuing crisis in the petroleum sector but without compromising food security. This opportunity to develop biofuels could only be transformed into real benefits if, alongside the development of biofuel channels, considerable efforts are invested mainly in the form of public decisions (implementation of the strategy, establishment of a legal framework, application of product standards, inclusion of smallholdings in biofuel production, protection of local populations, etc.), research and development (agricultural plants, the CO_2 sequestration potential of energy crops, ethanol esterification, etc.), and the adaptation of CDM methods in West Africa.

Acknowledgements

The authors would like to thank the Burkina Faso Ministry of Agriculture, Water and Fisheries Resources and the Burkina Faso Ministry of Mines, Careers and Energy for their contributions and help. This work was undertaken with the assistance of AGROPOLE,

the European Union, the German Financial Cooperation (KfW) and the German Technical Cooperation (GTZ). Its content is the exclusive responsibility of the authors and does not represent the point of view of these institutions.

References

[1] Lanser P, Dom C, Orivel F, Ouédraogo J-P Rapport de Pays Burkina Faso. Evaluation conjointe d'Appui Budgetaire General 1994–2004. International Development Department, School of Public Policy, University of Birmingham, Edgbaston, Birmingham mai 2006. www.idd.bham.ac.uk.

[2] Kimseyinga Sawadogo.La pauvreté au Burkina Faso: Une analyse critique des politiques et des stratégies d'intervention locales. 〈http://unpan1.un.org/intradoc/groups/public/documents/CAFRAD/UNPAN013234.pdf〉.

[3] Ministère des Mines des Carrières et de l'Energie (MMCE). Le secteur de l'énergie—Situation 2007 et perspectives. 12. 9 septembre 2008.

[4] Guengant J-P, Kamara Y Comment bénéficier du dividende démographique? La démographie au centre des trajectoires de développement dans les pays de l'UEMOA. Ouagadougou, Burkina Faso. Agence Française de Developpement (AFD). 56p. 2011.

[5] France.Cours du Baril de Petrole en $ Courant (WTI). 〈http://www.france-inflation.com/graph_oil.php#historique〉.

[6] Burkina Faso: Country Brief. 〈http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/BURKINAFASOEXTN/0,,menuPK:343886~pagePK:141132~piPK:141107~theSitePK:343876,00.html〉.

[7] FMI. Perspectives économiques régionales Afrique Subsaharienne. Etudes économiques et financières. Fonds Monétaire International. Avril 2010. 〈http://www.imf.org/external/french/pubs/ft/reo/2010/afr/sreo0410f.pdf〉.

[8] Société Nationale Burkinabé des Hydrocarbures (SONABHY). Rapport d'Activité. Ouagadougou. 83p. Avril 2008.

[9] Amigun B, Sigamoney R, von Blottnitz H. Commercialisation of biofuel industry in Africa: a review. Renewable and Sustainable Energy Reviews 2008;12(3):690–711.

[10] Blin J, Dabat M-H, Faugere G, Hanff E, Weismann N. Opportunité de Developpement des Biocarbutants au Burkina Faso 2008:166. 〈www.cirad.bf/doc/bioenergie-kfw-res.pdf〉.

[11] Krämer P The Fuel Wood Crisis in Burkina Faso—Solar Cookers As An Alternative. 〈http://www.solarcooking.org/Crisis.htm〉.

[12] Société Nationale d'Electricité du Burkina. Statistiques et chiffres caractéristiques. Burkina Faso. 2008. 〈http://www.sonabel.bf/statist/chiff_caract.htm〉.

[13] EIA. Annual Energy Outlook 2011. Energy Information Administration. DOE/EIA-0383(2010). Dec 2010.

[14] Société Nationale d'Electricité du Burkina (Sonabel). Rapport d'Activité 58p. 2009.

[15] Ministère du Commerce de la Promotion de l'Entreprise et de l'Artisanat. Annexe I à l'arrêté n° 08.002/MCPEA/SG/DGC du 10 janvier 2008 portant composition des structures de prix des hydrocarbures. Ouagadougou. 12p. 2008.

[16] European Commission. Europa Institution Policy. 〈http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32003L0030:FR:NOT〉.

[17] Harrabin R. EU rethinks biofuels guidelines. BBC News; 2008.

[18] World Bank. World Development Report 2008—Agriculture for Development. Washington, D.C. 394p. 2007.

[19] World Bank. Rural Transformation and Late Developing Countries in a Globalizing World. A Comparative Analysis of Rural Change, Executive summary. 23p. 2011. 〈http://siteresources.worldbank.org/AFRICAEXT/Resources/258643-1323805221801/RuralStruc_ExecSum_Final.pdf〉.

[20] World Bank. Country Brief: Burkina Faso. eStandardForum, Financial Standards Foundation. September 2, 2009. 〈http://www.estandardsforum.org/system/briefs/239/original/brief-Burkina%20Faso.pdf?1254987833〉.

[21] Laude JP. Document Politique de developpement des biocarburants au Burkina Faso. Ministère des Mines des Carrières et de l'Energie 2009;48 Octobre.

[22] Ministère des Mines des Carrières et de l'Energie (MMCE). Statistiques Burkina Faso. 2007.

[23] Augustus GDPS, Jayabalan M, Seiler GJ. Evaluation and bioinduction of energy components of *Jatropha curcas*. Biomass and Bioenergy 2002;23(3):161–4.

[24] Pramanik K. Properties and use of *Jatropha curcas* oil and diesel fuel blends in compression ignition engine. Renewable Energy 2003;28(2):239–48.

[25] Namasivayam C, Sangeetha D, Gunasekaran R. Removal of anions, heavy metals, organics and dyes from water by adsorption onto a new activated carbon from *Jatropha* husk, an agro-industrial solid waste. Process Safety and Environmental Protection 2007;85(2):181–4.

[26] Rug M, Ruppel A. Toxic activities of the plant *Jatropha curcas* against intermediate snail hosts and larvae of schistosomes. Tropical Medicine & International Health 2000;5:423–30 June.

[27] King AJ, He W, Cuevas JA, Freudenberger M, Ramiaramanana D, Graham IA. Potential of *Jatropha curcas* as a source of renewable oil and animal feed. Journal of Experimental Botany 2009:1–9.

[28] Jingura RM, Musademba D, Matengaifa R. An evaluation of utility of *Jatropha curcas* L. as a source of multiple energy carriers. International Journal of Engineering, Science and Technology 2010;2:115–22.

[29] Singh RN, Vyas DK, Srivastava NSL, Narra M. SPRERI experience on holistic approach to utilize all parts of *Jatropha curcas* fruit for energy. Renewable Energy 2008;33(8):1868–73.

[30] Deeba F, Kumar V, Gautam K, Saxena RK, Sharma DK. Bioprocessing of *Jatropha curcas* seed oil and deoiled seed hulls for the production of biodiesel and biogas. Biomass and Bioenergy 2012;40:13–8 May.

[31] Devappa RK, Makkar HP, Becker K. Biodegradation of *Jatropha curcas* phorbol esters in soil. Journal of the Science of Food and Agriculture 2010;90:2090–7.

[32] Chhinh N, Sriv T, San V, Va D Costs and benefits analysis of small scale *Jatropha curcas* plantation in Cambodia submitted to economy and environment program for Southeast Asia (EEPSEA). Final Technical Report. August 2010.

[33] Jongschaap REE, Corre WJ. Claims and facts on *Jatropha curcas* L.: *Jatropha curcas* evaluation, breeding and propagation programme. Wageningen. Plant Research 2007.

[34] Achten WM, Mathijs E, Verchot L, Singh VP, Aerts R, Muys B. *Jatropha* biodiesel fueling sustainability? Biofuels Bioproducts and Biorefining Special Issue: Sustainability 2007;1:283–91 December.

[35] Pandey VC, Singh K, Singh JS, Kumar A, Singh B, Singh RP *Jatropha curcas*: a potential biofuel plant for sustainable environmental development. Renewable and Sustainable Energy Reviews (16). 5.2870–2883.

[36] Le Faso.net.Burkina-Faso-SN-SOSUCO. 〈http://www.sucre-ethique.org/Burkina-Faso-SN-SOSUCO-Les.html〉.

[37] Nan L, Best G, Carvalho Neto CC. Integrated energy systems in China—the cold North eastern region experience. Rome: FAO; 1994.

[38] Bullock. Ethanol from Sugarcane. Mackay-Australia. Sugar Research Institute. 2002. 〈http://www.zeachem.com/pubs/Ethanol%20from%20Sugarcane.pdf〉.

[39] Sidibé SS, Blin J, Vaitilingom G, Azoumah Y. Use of crude filtered vegetable oil as a fuel in diesel engines state of the art: literature review. Renewable and Sustainable Energy Reviews 2010;14(9):2748–59.

[40] Vaitilingom G. Huiles végétales—biocombustibles diesel: influence de la nature des huiles et en particulier de leur composition en acides gras sur la qualité-carburant. Université d'Orléans; 1992.

[41] Vaitilingom G Extraction, conditionnement et utilisation des Huiles Végétales Pures Carburant: Rapport final. Cirad. octobre 2007.

[42] Asal S, Marcus R, Hilbert JA. Opportunities for and obstacles to sustainable biodiesel production in Argentina. Energy for Sustainable Development 2006;10(2):48–58.

[43] Yüksel F, Yüksel B. The use of ethanol–gasoline blend as a fuel in an SI engine. Renewable Energy 2004;29(7):1181–91.

[44] Communauté Economique des Etats de l'Afrique de l'Ouest (CEDEAO). White Paper for a Regional Policy on Access to Energy Services. 〈http://energyaccessafrica.org/index.php?option=com_content&view=article&id=157%3Ale-livre-blanc-de-la-cedeao-sur-lacces-aux-services-energetiques-&catid=45%3Aactualites&lang=en〉.

[45] Nonyarma E, Laude J-P. Cadrage de la Politique de Développement des Biocarburants au Burkina-Faso. Les biocarburants: facteurs d'insécurité ou moteur de développement? Ouagadougou 2009.

[46] Vaitilingom G. Utilisations énergétiques de l'huile de coton. Cahiers Agricultures 2006;15(n° 1):6.

[47] Ministère de l'Economie et des Finances du Burkina Faso. Presentation du Budget de l'Etat. 9p. 2009. 〈http://www.finances.gov.bf/SiteFinances/budget/note-budget2008.pdf〉.

[48] Deichmann U, Meisner C, Murray S, Wheeler D. The economics of renewable energy expansion in rural Sub-Saharan Africa. Energy Policy 2011;39:215–27.

[49] Comité Permanent Inter-Etats de Lutte contre la Secheresse dans le Sahel (CILSS). Biocarburants au Burkina Faso. Sécretariat Executif. 2007. 〈http://www.cilss.bf/predas/Activites%20par%20Pays/BF/16-BIOCARBURANT S%20au%20BF-Contraintes%20Atouts%20et%20%20Perspectives.pdf〉.

[50] Ballerini D, Alazard-Toux N. Les biocarburants: état des lieux, perspectives et enjeux du développement. Paris: Technip ed IFP Publications; 2006 348p.

[51] Phalan B. The social and environmental impacts of biofuels in Asia: an overview. Applied Energy 2009;86(Supplement 1):S21–9.

[52] Wicke B, Sikkema R, Dornburg V, Faaij A Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy (28). 1.193–206.

[53] Gueye B L'agriculture familiale en Afrique de l'Ouest, concepts et enjeux actuels. 2003.

[54] FAO. Volatilité des prix et sécurité alimentaire. Rapport 1. Rome. Comité de la Sécurité Alimentaire Mondiale,Groupe d'Experts de Haut Niveau sur la sécurité Alimentaire et la Nutrition (HLPE). 98p. Juillet 2011.

[55] BAfD/OCDE. Burkina Faso: Chiffres Clés. Perspectives économiques en Afrique. 2008 〈http://www.oecd.org/dataoecd/13/6/36746790.pdf〉.

[56] Van Eijck J. Transition towards *Jatropha* biofuels in Tanzania? An analysis with strategic niche management Leiden, the Netherlands: African Studies Centre; 2007.

[57] Food and Agriculture Organization.FAOSTAT - Burkina Faso. 〈http://faostat.fao.org/site/339/default.aspx〉.

[58] Dabat M-H. Les nouveaux investissements dans les agrocarburants: quels enjeux pour les agricultures africaines? Afrique contemporaine 2011;237:97–109.

[59] Hanff E, Dabat M-H, Blin J. Are biofuels an efficient technology for generating sustainable development in oil-dependent African nations? A macroeconomic

assessment of the opportunities and impacts in Burkina Faso Renewable and Sustainable Energy Reviews 2011;15:2199–209.
[60] Cadre Stratégique de Lutte contre la Pauvreté. Programme des Nations Unies pour le Developpement (PNUD). 139p. 2004. 〈http://www.pnud.bf/docs/CSLP.PDF〉.
[61] Lawrence R. How good politics results in bad policy: the case of biofuel mandates, environment and natural resources program. Harvard Kennedy School, Belfer Center for Science and International Affairs; 2010 September.
[62] Chang HJ Rethinking public policy in agriculture. Lessons from distant and recent history. Policy assistance series 7. Rome. FAO. 107p. 2009.
[63] Dauvergne P, Neville KJ. Forests, food, and fuel in the tropics: the uneven social and ecological consequences of the emerging political economics of biofuels. journal of Peasant Studies 2010;37(4):631–60.
[64] Vermeulen S, Cotula L. Over the heads of local people: consultation, consent, and recompense in large-scale land deals for biofuels projects in Africa. Journal of Peasant Studies 2010;37(4):899–916.
[65] Nazneen K, Cotula L, Hilhorst T, Toulmin C, Witten W. Can land registration serve poor and marginalised groups? London: International Institute of Environment and Development; 2005 30p.
[66] Coordination Sud. Agricultures familiales et sociétés civiles face aux investissements dans les terres dans les pays du Sud. Série Etudes et Analyses 2010:135. 〈www.coordinationsud.org/wp-content/uploads/coordination-web.pdf〉.
[67] Daho T. Contribution à l'étude des conditions optimales de combustion des huiles végétales dans les moteurs diesel et sur les brûleurs: cas de l'huile de coton. Ouagadougou: Université de Ouagadougou; 2008.
[68] Murugesan A, Umarani C, Subramanian R, Nedunchezhian N. Bio-diesel as an alternative fuel for diesel engines—a review. Renewable and Sustainable Energy Reviews 2009;13(3):653–62.